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THE LHC POMERON - will it end the *"Crisis in Fundamental Physics" ?* *

As I described in my talk last year -

- **The uniquely unitary Critical Pomeron is uniquely related to QUD* - a massless SU(5) theory with a bound-state S-Matrix that could be that of the Standard Model (SM).** (See also arXiv:0708.1306.)
- **A color sextet quark sector produces both EW symmetry-breaking & dark matter. It should appear, with hadronic-size x-sections, at the LHC** *& the $\mathbb{P}$ could be the main diagnostic* **- via FP420 et al.**

* *Quantum Uno/Unification/Unitary/Underlying Dynamics*

* *Presented at the 5th Manchester Forward Physics Workshop , Dec. 2007.*

I will outline the multi-regge argument that $\{$*perhaps*$\}$

QUD $\longrightarrow$ the SM high-energy S-Matrix.

The full program is enormously challenging & badly needs the extra interest / participation that LHC encouragement would bring.

My main focus will be on surrounding motivational issues & consequences. I will only briefly review the $\mathbb{P}$ physics & will not discuss at all, related Cosmic Ray & Tevatron evidence. As I will describe,

- **not only may QUD solve existing SM puzzles** *(& cosmology problems - it has zero vacuum energy),*

- **because the** $\{$*IR-anomaly based*$\}$ **physics is conceptually & philosophically radical wrt the current theory paradigm,**

- **it may also provide a way out of the percieved "crisis" in the current formulation of theory.**

Arguments by leading theorists $(Weinberg, Susskind, \&\ others)$ *have led to what Smolin calls "A Crisis in Fundamental Physics"* *- epitomized by asking, based on the "string-theory landscape",*

" With an infinity of universes proposed, and more than 10^{400} theories, is experimental proof of physical laws still possible? "

A retreat to the "anthropic principle" **- physical parameters are determined by the existence of life -** *is a common response.*

Adding to the bewilderment *(says Smolin), in the 35 years since the formulation of the SM,* **all proposals for "new physics"**

- including GUTS, supersymmetry, technicolor, string theory & (most recently) extra dimensions ...

have failed to make any contact with experiment - even while introducing a wide variety of interactions,* particles, & new parameters.

$^{*}The\ last\ discovery\ of\ a\ new\ interaction >> 35\ years\ ago$!!

Theoretically, there are far too many (ill-defined) candidate new theories, while experimentally there are none !

Searching for new theories via the symmetry-based aesthetics championed by much of the theory community has not found a focus, although there has been no shortage of **imagination !!**

- *Doubling the number of particles to achieve supersymmetry,* **when not a single partner has been seen,** *& adding extra dimensions that* **"curl up"** *out of our sight both seem far-fetched*[*] *to* **"real world"** *theorists, as well as many experimenters.*

There is a much concern that a major change may be needed in the paradigm underlying current theory.

[*] *If neither appears at the LHC, this will be the historical perspective.*

In 1999, David Gross said *(wrt QCD & the S-Matrix bootstrap program)*

"We now know that there are an infinite number of consistent S-Matrices that satisfy all the sacred principles *(particularly unitarity).* **One can take any non-abelian gauge theory, with any gauge group, and many sets of fermions ... "**

$=>$ *Unitarity is irrelevant !!* **This is "breathtakingly misleading".**

$\{Bill\ Clinton\}$

1. *Gauge theory S-Matrices can only be calculated perturbatively.*
2. *In D=4 the perturbation expansion for every field (& string) theory is wildly divergent &, most likely, can not be summed.*
3. *There is no non-perturbative formulation of any theory which can derive scattering amplitudes - let alone discuss unitarity.*

Gross also said that the regge region is merely*

"an interesting, unsolved, & complicated problem for QCD"

that had been **"unduly emphasized".**

* $Experimenters\ working\ on\ diffraction\ have\ lived\ with\ this\ attitude\ for\ a\ long\ time.$

If I am right, the widely held views described by Gross could not be further from the truth.

- **Regge-region unitarity** *is deeply related to other fundamental problems in the formulation of QCD & is central in the* **construction of a fully unitary gauge theory.**

- *The viewpoint that solving difficult problems in QCD is not fundamental for going beyond the SM* **may be a major factor in producing the "theory crisis".**

- *That progress will come via inspired guesses for the missing* $\{$*thought to necessarily be*$\}$ *short-distance, physics* **- with experimental verification coming from related rare processes -** *has yet to be confirmed**. **In fact,**

large-distance physics (QCD) is not well understood.

* *There is* **NO** *historical precedent.*

QCD PROBLEMS

There are three interconnected, unresolved, problems for the standard formulation of QCD.

1. The Spectrum of States -

- *The conventional wisdom is that the physical states are determined by color confinement & (when quarks are involved) chiral symmetry breaking. Neither principle has been proved, but there is no experimental violation of either.*
- **BUT,** *if color confinement is the only feature constraining the field theory degrees of freedom appearing in physical states, then glueballs should be everywhere.*

NOT A SINGLE GLUEBALL HAS BEEN SEEN (unambiguously) IN ANY EXPERIMENT.

- *Apparently, there is a major limitation on the degrees of freedom.*

Physical states must contain quarks ???

2. The Parton Model -

- **Factorization theorems say that leading-twist perturbation theory is consistent with the parton model.** *However, even though it is the basis of all pertubative applications, there is*

no derivation of the parton model in QCD.

- *A true parton model,* **as originally envisaged by Feynman,** *requires that*

infinite momentum hadrons have quark/gluon wave functions.

- **This is a very intricate requirement that has no reason to be true if there is a non-trivial, confining, vacuum** *

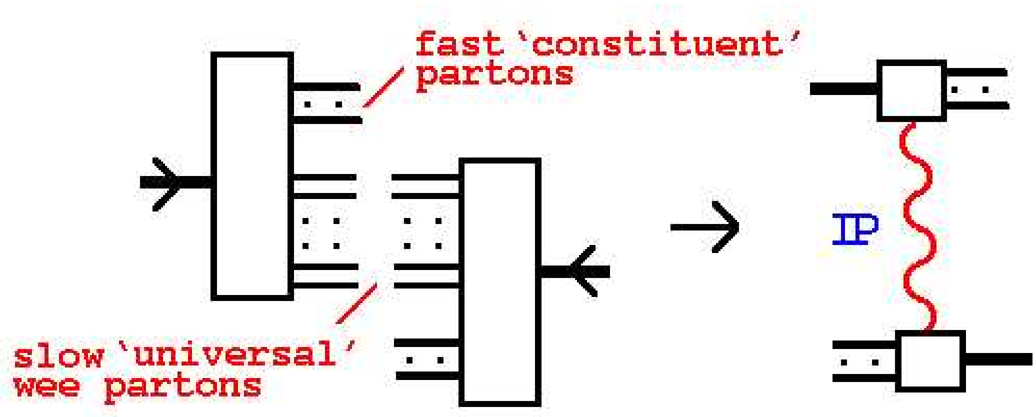
* *although it is probably essential for asymptotic freedom to be maximally applicable.*

For hadrons to have well-defined $\{\infty - momentum\}$ *wave-functions -*

- **"wee partons"** *(with finite momentum in the* ∞*-momentum frame)* **must carry the "vacuum properties" of the theory.**

$\Longrightarrow$ **hadrons have a "universal" wee parton component.**

The wee partons in a hadron dominate pomeron exchange



For wee partons to be universal, the $\mathbb{P}$ must have the factorization properties of a Regge Pole.

3. The Pomeron -

A priori, large $k_\perp$ $\rightarrow$ the perturbative BFKL $\mathbb{P}$ + an odderon.

1. *There is no* **unambiguous** *evidence for the* **BFKL** $\mathbb{P}$ *&* **zero** *evidence for the odderon.*
2. *The* **BFKL** $\mathbb{P}$ **violates s- & t-channel unitarity,** *& higher-order corrections very likely make the problem worse.*
3. *Because the* **BFKL** $\mathbb{P}$ *is not a regge pole*
   - **Wee parton factorization is absent.**
   - **Reggeon Field Theory (RFT) can not be used.**

Experimentally, **at small $k_\perp$, the $\mathbb{P}$ couples directly to quarks** *(c.f. total cross-sections) & has the factorization properties of a regge pole.*

Apparently, BFKL gluons are absent in physical amplitudes & quarks are the essential element of the states.

Uniquely, the RFT Critical $\mathbb{P}$ *satisfies both* **s- & t-channel multiparticle unitarity** *& it is built up as a* **regge pole + interactions.**

To obtain the Critical $\mathbb{P}$ via **gauge theory reggeon diagrams,** *is* **"highly non-trivial" -**

- *a very special version of QCD* **(QCD$_S$)** *is required, which then*
- *has to be embedded in a* **unique** *larger theory -* **QUD.**

Alao, novel dynamics is involved* *- relating to the controversy (30 years ago) wrt a* **unitary supercritical RFT phase.** *In this phase a*

" $\mathbb{P}$ condensate" *is produced by wee partons. This is the key to the Critical $\mathbb{P}$ & "universal wee partons"* **- in both QCD$_S$ & QUD.**

First, the basic properties of QUD -

* *Involving massless fermion anomalies that exploit the Gribov quantization ambiguity wrt Gauss's law.*

THE PATH TO QUD

1. *Initially, supercritical RFT is matched with SU(3) color & the Critical $\mathbb{P}$ is shown to occur when asymptotic freedom is "saturated"* $\leftrightarrow$

   6 color triplet quarks $+$ **2 color sextet quarks** $\leftrightarrow$ **"QCD$_S$"**

2. $W^{\pm}$ & Z^{0} *eat the "sextet pions" & EW symmetry breaking occurs -* **without any new interaction** *(that the EW scale is the QCD sextet chiral scale is consistent with* **Casimir scaling !!***)*

3. **To cancel the EW anomaly & to generate masses, the sextet sector is embedded in a left-handed unified theory.**

4. **The sextet sector + asymptotic freedom + anomaly cancelation** **uniquely** requires SU(5) gauge theory & the fermion representation

$$\mathbf{5 + 15 + 40 + 45}^{*} \quad \leftrightarrow \quad QUD$$

QUD contains **QCD**$_S$ & under $SU(3)\otimes SU(2)\otimes U(1)\ \rightarrow$

$$\mathbf{5}=(\mathbf{3},\mathbf{1},-\tfrac{\mathbf{1}}{\mathbf{3}}))^{\{3\}}+(\mathbf{1},\mathbf{2},\tfrac{\mathbf{1}}{\mathbf{2}})^{\{2\}}\ ,$$

$$\mathbf{15}=(\mathbf{1},\mathbf{3},\mathbf{1})+(\mathbf{3},\mathbf{2},\tfrac{\mathbf{1}}{\mathbf{6}})^{\{1\}}+(\mathbf{6},\mathbf{1},-\tfrac{\mathbf{2}}{\mathbf{3}})\ ,$$

$$\mathbf{40}=(\mathbf{1},\mathbf{2},-\tfrac{\mathbf{3}}{\mathbf{2}})^{\{3\}}+(\mathbf{3},\mathbf{2},\tfrac{\mathbf{1}}{\mathbf{6}})^{\{2\}}+(\mathbf{3}^*,\mathbf{1},-\tfrac{\mathbf{2}}{\mathbf{3}})+(\mathbf{3}^*,\mathbf{3},-\tfrac{\mathbf{2}}{\mathbf{3}})+(\mathbf{6}^*,\mathbf{2},\tfrac{\mathbf{1}}{\mathbf{6}})+(\mathbf{8},\mathbf{1},\mathbf{1})\ ,$$

$$\mathbf{45}^*=(\mathbf{1},\mathbf{2},-\tfrac{\mathbf{1}}{\mathbf{2}})^{\{1\}}+(\mathbf{3}^*,\mathbf{1},\tfrac{\mathbf{1}}{\mathbf{3}})+(\mathbf{3}^*,\mathbf{3},\tfrac{\mathbf{1}}{\mathbf{3}})+(\mathbf{3},\mathbf{1},-\tfrac{\mathbf{4}}{\mathbf{3}})+(\mathbf{3},\mathbf{2},\tfrac{\mathbf{7}}{\mathbf{6}}))^{\{3\}}+(\mathbf{6},\mathbf{1},\tfrac{\mathbf{1}}{\mathbf{3}})+(\mathbf{8},\mathbf{2},-\tfrac{\mathbf{1}}{\mathbf{2}})$$

The triplet quark and lepton sectors $\{not\ asked\ for\ !\}$ *are* **amazingly close to the SM !!** *There are* **3** *"generations",* $\{1\},\{2\},\{3\}$. *The SU(2)xU(1) quantum numbers are not quite right, but* **the lepton anomaly is correct & there are 3 sets of** $q/\bar{q}$ **pairs with charges** $\pm\frac{2}{3}\ \&\pm\ \frac{1}{3}$.

Beyond *the SM generations, there is* **only**

1. **A sextet quark sector** $\rightarrow$ **EW symmetry breaking & dark matter!**
2. **A "lepton-like" octet quark sector** $\{$*embedded in bound states*$\}$
   $\rightarrow$ **SU(5) invariant leptons & hadrons in SM generations.**
3. **A pair of exotically charged quarks.**

Nothing else !!

The Crucial Dynamics *selects a very limited* $\{$*anomalous*$\}$ *subset of the gauge field degrees of freedom.* **The $\mathbb{P}$ condensate is produced by**

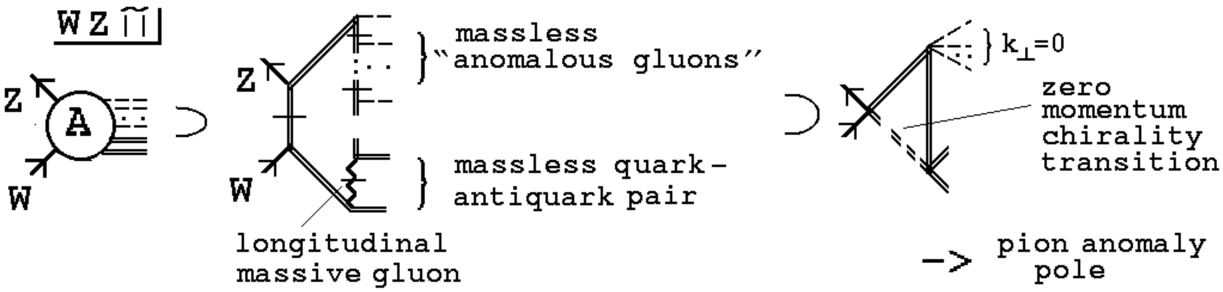
wee gluon reggeon divergences *coupled via* **reduced fermion loops that contain IR anomalies** *due to zero momentum chirality transitions* $\{cf.\ condensates\}$**.**

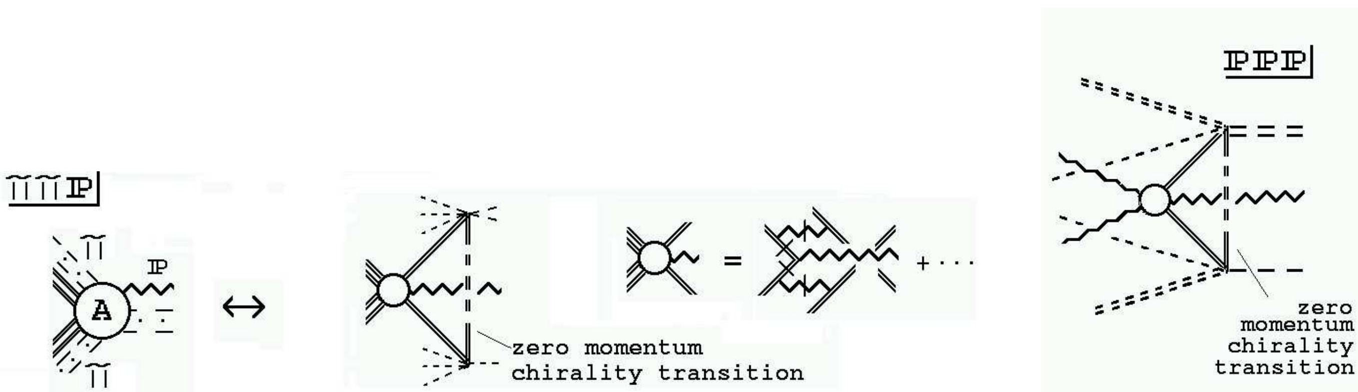
- *The anomalies are dependent on the symmetry restoration & cut-off removal procedure & occur* **only in the S-Matrix.**
- **All fermions** *must be* **massless &** *there must be*
- *an* **IR fixed-point** *($\leftrightarrow$ max no. of fermions).*

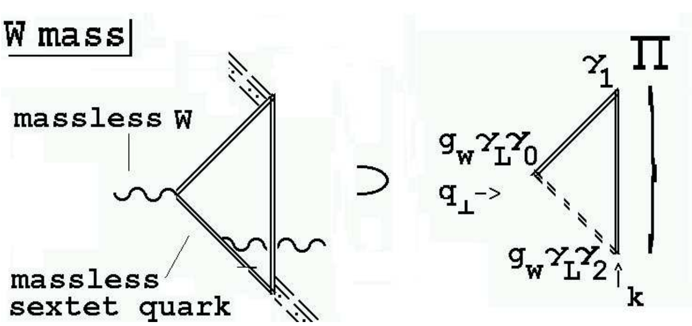
In QCD_S, a vector theory, the divergences produce a spectrum with confinement & chiral symmetry, plus color parity breaking for the $\mathbb{P}$.

Remarkably, in QUD, which is vector-like only wrt SU(3)xU(1), the anomaly divergences reproduce the interactions of the SM.

Reggeon interaction anomalies are produced when massless fermions in large loops are placed on-shell by a multi-regge limit, e.g.





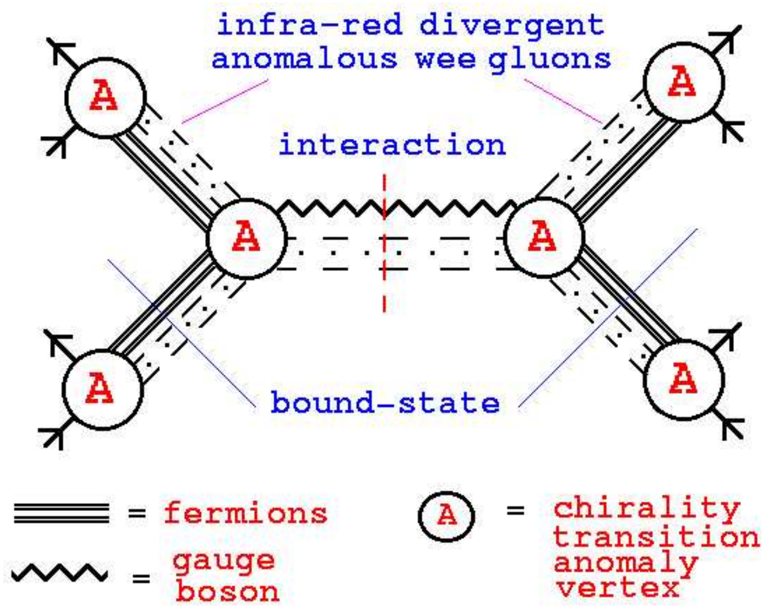


$\sim g_w^2\, \varepsilon_{2301} k_3\, q_2^2 / q_\perp^2$

Very briefly -

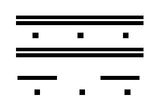
∞-momentum bound states & interactions are constructed similarly in QCD$_S$ and QUD - via multi-regge amplitudes containing **IR divergent** gauge bosons **coupled to anomalies.**

Restoring the gauge symmetry **in steps** & extracting anomaly divergences -

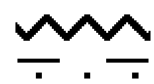


The “simplest” amplitude

bound-states *appear first as* **Goldstone boson** *“anomaly poles” formed as* **SU(2) color zero** *combinations of fermions in a “universal anomalous wee gluon” condensate *.*



interactions *are color zero combinations of a finite transverse momentum gauge boson in the same wee gluon condensate *.*



* *As the $\mathbb{P}$ becomes critical, via $SU(3)$ color, the anomalous wee gluons $(\leftrightarrow$ $\mathbb{P}$ condensate$)$ become dynamical.*

QCD$_S$ - *States & Interactions*

The physical states are

1. **triplet mesons & nucleons**
2. **sextet "pions" & "nucleons" ($P_6 \& N_6$)**
3. **no** *hybrid sextet/triplet quark states*
4. **no** *glueballs.*

Consistent with, but much less than, confinement & chiral symmetry breaking.

The sextet pions are eaten by $W^\pm$ & Z^0 *& so the* **only new states** *are sextet nucleons.* **The N_6 will be stable & dominate UHE x-sections**

$\longrightarrow$ **Dark Matter !!**

The interaction is the Critical $\mathbb{P}$ $=>$ **the parton model, no BFKL pomeron, & no odderon.**

Compared to conventional QCD, the states are fewer & the interaction simpler - in agreement with experiment !!

QUD - *States & Interactions* *(briefly & very preliminary)*

Parity violation by fermion loops **exponentiates** *all anomaly divergences involving* **left-handed** *reggeon couplings* $\Longrightarrow$

Anomalies $\rightarrow$ SU(3) COLOR SINGLET strong interaction !!

Wee gluon anomaly interactions give **left-handed** $W^{\pm}$ *&* Z^{0} *exchanges a mass* *($\leftrightarrow$ mixing with sextet pions).*

The lepton-like octet quarks produce SU(5) invariance.

- **Leptons** *are bound states of elementary leptons & "octet pions" (i.e. large* $(k_{\perp}, \pm E)$ *octet pairs)* $\rightarrow$ **Standard Model generations.**
- **hadrons form similarly** *& EW anomaly* $\Longrightarrow$ $(?)$ *3 generations.*
- **SU(2)$_L \otimes$U(1) appears at low** $k_{\perp}$ (via sextet flavor).
- *Octet SU(3) reality* $=>$ *octet* π*'s have no* $\mathbb{P}$ *coupling* $=>$ **leptons have no strong interaction & no IR SU(3) mass generation.**

$\rightarrow$ **(??) interactions & states of the Standard Model.**

That the anomaly-dominated **bound-state S-Matrix** *of a very small coupling, massless, fixed-point, field theory is the* **origin of the Standard Model** *is a radical proposal that could have many desirable consequences.*

It could also be the change in paradigm needed to end the

“crisis in fundamental physics”.

If my arguments can be followed through -

1. *QUD is self-contained - with only SM Interactions !!*

2. *The only new physics is the strong interaction sextet sector - giving EW symmetry breaking, dark matter & unification without supersymmetry !!*

3. *Parity conservation of the strong interaction & parity violation of the weak interaction are naturally explained.*

4. *No off-shell amplitudes & no Higgs field $=>$ symmetries & masses are bound-state S-Matrix properties. (Anomaly interactions mix the reggeon states &, presumably, introduce parameters.)*

5. *Color factors produce a wide range of scales & masses that could produce the SM spectrum - there is no conflicting symmetry.*

6. *Small neutrino masses should be due to the underlying small coupling.*

7. *There is no proton decay, but the experimentally attractive SU(5) Weinberg angle should hold!*

8. *Because QUD is an asymptotically free, massless, fixed-point theory,*

it has no vacuum energy & would induce *Einstein gravity with zero cosmological constant* (Holdom).

What Should be Seen at the LHC ?

There will be obvious large cross-sections. Most immediately -

- *multiple vector boson & jet x-sections* **much, much, larger** $\longrightarrow$ *EW scale* $< p_{\perp} >$. **But,** *black holes, sphalerons ... ???*

- $N_6 \bar{N}_6$ *pair production* $\{$*dark matter*$\}$ *- with* $m_{N_6} \sim 500\ GeV$ *?* **But,** *missing* $E_T \sim 500 GeV$ *will be common* & the low energy N_6 hadronic x-section (in a calorimeter) is probably small.

- $P_6 \bar{P}_6$ *pair production (if the* P_6 *is not too unstable).* But, is a massive charged particle, with a large production x-section direct evidence for a sextet sector ??

The double $\mathbb{P}$ x-section could provide the most definitive early evidence for the sextet sector.

- *With the $\mathbb{P}$'s detected via Roman pots, the environment is clean.*

- $W\&Z$ **pairs will be produced in the double $\mathbb{P}$ x-section via sextet pion anomaly poles.** $\{$*As pion pairs dominate the double $\mathbb{P}$ x-section at low mass, so $W\&Z$ pair production will dominate the x-section at the EW mass scale.*$\}$

- *When $|k_\perp|$ is EW scale, double $\mathbb{P}$ $W\&Z$ pairs will give jet x-sections that, at large $k_\perp$, are comparable with the non-diffractive jet x-sections predicted by standard QCD.*

- *The* $\{\mathbb{P}\,W^+W^-\mathbb{P}\}$ & $\{\mathbb{P}\,Z^0Z^0\mathbb{P}\}$ vertices will vary slowly with $k_\perp$, but hadron/$\mathbb{P}$ vertices have strong $k_\perp$-dependence

$\Longrightarrow$ **an extremely large x-section at small t.**

- *In the low luminosity running, the "extremely large x-section" could be detected by* **TOTEM/CMS**

- *There could be spectacular events in which protons are tagged & only large E_T leptons are seen in the central detector.*

- **FP420** *will take over during the high luminosity running & should surely see the enhanced x-section - if it is present !!*

- **With the planned parameters for FP420, the $W\&Z$ pair x-section will overwhelm all other physics.**

A large double $\mathbb{P}$ x-section for $W\&Z$ pairs

$=>$ **longitudinal components of $W\&Z$ have direct strong interactions** $=>$ **existence of the sextet sector !!!**

After $\mathbb{P}$, W/Z, & jet physics has established that sextet quark physics is discovered, **the search for "Dark Matter" will become all important.**

The x-section for **double $\mathbb{P}$ production of $\{$stable$\}$ $N_6\bar{N}_6$ pairs** *could be large enough to be seen.*

- *Tagged protons $=>$ a very massive $\{\sim 1\ TeV\}$ state was produced.*
- *No charged particles are seen in any of the detectors.*
- *The low energy N_6 hadronic x-section will, probably, be small but some hadronic activity may be seen in the central calorimeter*
- *Charged lepton comparison would allow a separation wrt the multiple Z^0 production of neutrinos.*

If the P_6 is relatively stable, & not too different in mass $\{$*which I think should be the case*$\}$, it would be much simpler to first detect $P_6\bar{P}_6$ pairs